VIII

CHEMISTRY OF THE INTERPLANETARY DUST

Physics, Chemistry, and Dynamics of Interplanetary Dust
ASP Conference Series, Vol. 104, 1996
Bo A. S. Gustafson and Martha S. Hanner (eds.)

The Elemental Composition of Interplanetary Dust

D.E. Brownlee
Dept. of Astronomy
University of Washington
Seattle, WA 98195
Brownlee@astro.washington.edu

ABSTRACT Analyses of recovered samples of interplanetary dust have provided direct data on the bulk elemental composition of interplanetary dust over the 5μm to 1mm size range. The majority of particles have compositions similar to the bulk composition of chondrites although C and some trace volatile elements are often found in excess of CI abundances. Some individual particles have distinctly non-chondritic compositions. In most cases these particles contain large mineral grains.

1. Introduction

Elemental composition is a fundamental property of interplanetary dust that must be considered in models of the origin, evolution and overall properties of the meteoritic complex. This paper will review the overall composition of collected particles of interplanetary dust (IDP) and the basic limitations of the data. The published data on IDPs includes stratospheric particles as small as 5μm diameter and particles as large as a millimeter collected from polar and deep sea sediments. The composition data have been obtained by a variety of techniques including the electron microprobe, x-ray fluorescence, neutron activation, and proton induced x-ray emission. In general, it is found that typical IDPs have a limited range of compositions roughly centered on the mean composition of chondritic meteorites. In most particles the majority elements match chondritic abundances within a factor of three. Where large deviations from cosmic abundances occur, it is usually in particles dominated by large mineral grains such as sulfides, Mg silicates, FeNi metal, phosphides or carbonates

2.0 The Data

2.1 Stratospheric IDPs

Airborne IDPs collected in the stratosphere provide probably the least biased set of interplanetary particles for analysis. Because of the low flux and contamination considerations, IDPs collected in the atmosphere are usually in the 5μm to 50μm size range and most are 10μm in diameter. The collected stratospheric IDPs appear to be an excellent sampling of the 10μm size meteoroids although some particles break-up due to the stresses of atmospheric entry and collection and some of the higher velocity and/or larger particles melt due to atmospheric heating. Any meteoroid type that would either not be recognized or otherwise not be included in the collections probably represents less than 10% of the 10μm meteoroid population entering the Earth's atmosphere. Although this fraction cannot be accurately determined, it is estimated on the basis of the lack of strong selection effects of entry survival and the existence of strong criteria for distinguishing meteoritic particles from terrestrial materials. Unlike particles collected on the ground, stratospheric samples do not usually have to be distinguished from a significant background of terrestrial material and they have little chance to be altered by surface weathering processes. There is evidence that some samples do however pick up contamination during their stratospheric residence (Presper et al. 1993, Jessberger et al. 1992) but this appears to only effect trace elements , Br for example. Studies of the major element abundances of 10μm stratospheric IDPs show that most elements match the abundances of CI chondrites within a factor of two (Schramm et al. 1993). Analyses of large numbers of particles show peaking of compositions usually with only modest offsets from CI abundances. Some elements do, however, have abnormally large dispersions. Sulfur and Ca show wide abundance ranges due to their concentration in phases such as FeS and carbonates. Many particles show Ca and S depletions relative to CI abundances of a factor of two or more. Rare IDPs, however, have large "excesses" of these elements because they are largely composed of sulfide or Ca-rich minerals. If the data from many particles are combined, the depletions and excesses largely compensate for each other. Carbon is an element that is commonly found at more than a factor of two above CI abundances (Thomas et al, 1993). Carbon is highly fractionated among classes of chondrites at it is significant many IDPs have higher carbon abundances that the most carbon-rich meteorites. It is not clear that the carbon in IDPs is carried in volatile compounds but several volatile trace elements including Zn appear to be systematically enhanced in IDPs (Flynn et al 1993).

2.2 Deep Sea and Polar Ice Particles

Particles with sizes larger than 100 μm fall to Earth with a frequency less than $1m^{-2}yr^{-1}$. They are too rare to effectively captured in the atmosphere but they can be collected from the "ground" in special locations that combine long exposure time and low "contamination" by terrestrial particles with similar sizes and physical properties. Some deep sea sediments and polar ice are ideal collection sites and larger numbers of particles up to millimeter size have been recovered (Kurat et al. 1994; Maurette et al. 1993). Many of the recovered particles larger than 100μm diameter were strongly heated during atmospheric entry. The most easily identified extraterrestrial particles are spherules. These particles were heated above melting points >1200 C, they are highly depleted in volatiles such as Na, S, C and Rb. In addition, the spherules are depleted to various degrees in Ni and other siderophile elements. Isotopic fractionation in the spherules is indicative of evaporative loss of approximately 90% of the pre-atmospheric mass (Herzog et al. 1994). Unmelted particles (true micrometeorites) are also found up to millimeter size but they cannot be considered to be an unbiased samples. Among these samples there is bias favoring high melting point, strength and ability to survive and be recovered from the deep sea or polar ice environments. Highly fragile particles would not survive. The relatively high abundance of Mg olivine in large unmelted micrometeorites may be the result of high melting point favoring atmospheric survival. The large particles are, however, of extraordinary importance because they are the transition between "dust" and larger meteoroids. Their dynamical processes such as collisional and Poynting-Robertson evolution may significantly differ from smaller sizes. They have may have different origins and they surely have different lifetimes than small particles. A full understanding of the meteoroid complex requires knowledge of all particle sizes. From a purely mass sampling aspect, the larger polar ice and deep sea samples are also important because the larger particles are equivalent in mass to >100,000 typical IDPs collected in the stratosphere. The ice particles show systematic depletions of Ca, Co, S and Ni, and some enrichments in Br, K and Au. Some of these effects are probably are related to solution effects caused by weathering in and on the ice while others are indigenous properties.

2.3 Space Collections

Many particles have been collected as melted and unmelted debris in impacts onto spacecraft (Zolensky et al, 1994) Collectors have included metal, plastic *thermal blankets and specially designed capture cells. Most of these particles are* strongly modified during hypervelocity capture and in all cases is only possible to analyze a portion of the meteoroid. The collected meteoroid is usually accompanied by a significant amount of collection substrate which complicates accurate compositional analysis. When only of a fraction of a meteoroid survives impact there is no way to determine if its composition is representative of the entire original meteoroid. In some cases it appears that there is bias favoring high melting point materials such as Mg silicates such as forsterite. The major compositional groups seen in ground and atmospheric collections appear to be represented in the space collections although presently, compositional comparisons are relatively qualitative in nature. Improved techniques may provide excellent comparative data in the future.

3. Summary

The sets of extraterrestrial particles collected from the air and from surface deposits provide a powerful source of data on the composition of IDPs in the 5µm to mm size range. The overwhelming result is that typical particles have approximately chondritic elemental abundances. In most cases this is the result of mixing of many mineral grains plus amorphous materials that together yield approximately chondritic abundances even for particles only microns in size. Significant deviations from chondritic abundance are caused by the presence of large mineral grains. The most common deviations are usually caused by the presence of large Fe sulfides, pyroxene, olivine or other phases. Some particles dominated by hydrated silicates show strong depletions in Ca. Although not proven, it is likely that large enough collections of particles from a particular parent body would give close to chondritic elements for most major and minor elements.

For distinguishing different particle classes that might have genetic implications, it does not appear that elemental composition is a strong discriminator. Small samples of primitive solar system materials, to first order, tend to have similar compositions with scatter due to size-scale dependent inhomogenities in their parentbodies. Thomas et al. (1995) have shown that considerable insight into these inhomogenities within IDPs can be obtained by the analysis of so-called "cluster" particles that fragment into large numbers of >5μm components during collection in the stratosphere. Compositional ranges in these particles are similar to the overall range of individually collected particles. The natural level of compositional variation of nanogram particles produce a "noise" background that complicates accurate comparison with meteorite groups where characteristic compositions are derived from much larger samples. Physical properties such as structure and mineralogy do provide strong clues to origin and evolutionary processing (Klock and Stadermann 1994) but at least to first order, elemental compositions do not seem to be highly diagnostic properties. This is in contrast to meteorites where elemental compositions are an important criteria for classification.

References

Flynn, G. J., Sutton, S. R., and Bajt, S. 1993, Lunar Planet Sci. 24,495.

Jessberger, E.K., Bohsung, J., Chakaveh, S. Traxel, K. 1992, EPSL, 112, 91.

Herzog, G. F., Hall, G. S., Brownlee, D. E. 1994, Geochim. Cosmochim. Acta. 58, 5319.

Klock, W., and Stadermann, F. J. 1994, AIP Conf Proc. 310, 51.

Kurat, G. Koeberl, C., Presper, T. Brandstatter, F.Maurette, M. Geochim. 1994, Cosmochim. Acta.58, 3879.

Maurette, M., Kurat, G., Perreau, M., Engrand, C. 1993, Microbeam Analysis 2, 239.

Presper, T. Kurat, G. Koeberl, C. Palme, H., Maurette, M. 1993, Lunar Planet Sci.24 1177.

Schramm, L. S., Brownlee, D. E., and Wheelock, M. M. 1989, Meteoritics 24, 99.

Thomas, K, L., Blanford, G. E., Keller, L, P., Klock, W.,and McKay, D. S. 1993, Geochim. Cosmochim. Acta 57, 1551.

Thomas, K. L. et al. 1995, Geochim. Cosmochim. Acta 59, 2797.

Zolensky, M., et al. 1994, AIP Conf Proc. 310, 291.